

MAGNETITE FROM ALH84001 CARBONATE GLOBULES: EVIDENCE OF BIOGENETIC SIGNATURES?

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The Debate The occurrence of fine-grained magnetite in the Fe-rich rims surrounding carbonate globules in the martian meteorite ALH84001 was originally described in [1]. It was suggested by [1] that the presence of fine-grained magnetite (occurring with fine-grained carbonate and Fe-sulfides) could be explained by biogenic processes. On Earth, magnetotactic bacteria produce intracellular magnetite [2 and references therein]. When magnetotactic bacteria die, these magnetite grains can be deposited and preserved in sediments. In general, three morphologies of biogenic magnetite particles have been observed: roughly cuboidal [2, 3], parallelepipedal (rectangular in the horizontal plane) [2, 4], and arrow-head shaped [2, 5]. These magnetites are usually in the single domain (SD) size range (~30-120 nm) [e.g., 2]. Magnetite morphology is not unequivocally diagnostic for its biogenicity; the cuboidal form of magnetite is common in inorganically-formed magnetites while the parallelepiped and arrow-head forms of magnetite are more likely signatures of biogenic activity [2]. Magnetite particles found *in situ* in ALH84001 carbonate globules ranged from ~10-100 nm in size and are cuboid, teardrop, and irregular in shape [1].

The association of fine-grained magnetite, carbonate, and Fe-sulfides could also be explained by inorganic processes [1]. Recent work by [6] suggests that elongated magnetites within ALH84001 carbonates are formed by inorganic, high temperature processes. A controversy exists in that both biogenic and inorganic mechanisms have been proposed to describe the formation of magnetite grains in ALH84001. In order to address this debate, we present results describing magnetite extracted from ALH84001 carbonate globules.

Methods Two ALH84001 chips containing carbonate globules were immersed in ~20 µl of 20% acetic acid at ~50 °C for 72 and 96 hours. The residual chips were removed from the acid; the acid was placed on carbon-coated TEM (transmission electron microscope) grids and allowed to evaporate. These grids were examined at 160 and 200 kV using a JEOL 2000 FX TEM equipped with a Link System IV energy dispersive x-ray spectrometer.

Results Thousands of magnetite grains in clumps or groups were found on the TEM grids (Fig. 1). The magnetite ranges from ~10-200 nm in size (in the longest dimension); most particles have crystal faces although some appear to be etched. Magnetite morphology includes cuboidal-, parallelepiped-, teardrop-, irregular-, hexagonal-, and elongated-shaped crystals. Cuboidal and irregular magnetites were the most common; few elongated magnetites were observed. Parallelepiped-shaped magnetites are shown in Fig 2 (arrows); teardrop-shaped magnetite with characteristic 0.48 nm basal spacing is shown in Fig 3. Although rare (<<1%), elongated magnetites were also observed (arrow, Fig 4). For comparison, ALH84001 parallelepipedal magnetites are shown *in situ* within a carbonate grain (Fig 5), and chains of aligned parallelepipedal magnetites are shown within magnetotactic bacteria strain MV-1 (Fig 6.). Martian parallelepipedal magnetite crystals (n=22) range from 20-80 nm in length (average 37 nm) and 12-53 nm in width (average 24 nm); the size range of terrestrial biogenic parallelepiped-shaped magnetite (n=89) is almost identical to that of the martian particles (Fig 7). Furthermore, the slope of the width/length best-fit line is nearly identical. However, the average size of terrestrial biogenic parallelepipedal magnetites is larger than that from ALH84001 (53 nm and 35 nm). Twelve of the 22 martian parallelepipedal magnetites fall within the SD magnetite range; ten fall within the superparamagnetic (SP) size range.

Biogenic? The parallelepipedal and teardrop shapes of the martian magnetites deviate from the typical inorganic magnetite morphologies [e.g., 2]. Although not conclusive for biogenic activity, magnetites with these distinctive shapes are strongly suggestive of biominerals. Fifty-four per cent of parallelepipedal magnetites are in the SD range, the common size range for terrestrial biogenic magnetite.

Inorganic? The large size range of ALH84001 magnetite grains is not typical for terrestrial magnetite found in sediments; however, magnetites in terrestrial sediments have not experienced the same history (e.g., multiple shock and heating events) as ALH84001 [7]. Rare elongated magnetites are purported to have formed inorganically at high temperatures [6]. Irregular and cuboid magnetites may be suggestive of inorganic processes [e.g., 2].

ALH84001 magnetites may be the remnants of a complex system that includes a mixture of both biogenic and inorganic processes. Although biomarkers in ALH84001 may be difficult to identify, parallelepipedal and teardrop magnetite may be clues to a complex, and partially biogenic, martian history.

References: [1] McKay *et al.* (1996) *Science* **273**, 924. [2] Bazylinski and Moskowitz (1997) in *Geomicrobiology: Interactions between Microbes and Minerals* (Banfield and Nealson, eds.), 181. [3] Balkwill *et al.* (1980) *J. Bacteriol.* **141**, 1399. [4] Bazylinski *et al.* (1988) *Nature* **334**, 518. [5] Thornhill *et al.* (1994) *FEMS Microbiol. Lett.* **115**, 169. [6] Bradley *et al.* (1996) *GCA* **60**, 5149 [7] Treiman *Meteoritics*, in press. [8] Sparks *et al.* (1990) *EPSL* **98**, 14.

